HYSLOP

Frequency Measurements in Wireless Telegraphy

Physics

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FREQUENCY MEASUREMENTS IN WIRELESS TELEGRAPHY

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BY

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A. B. Knox College, 1908

THESIS

Submitted in Partial Fulfillment of the Requirements for the

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WILLIAM HENRY HYSLOP

ENTITLED "FREQUENCY MEASUREMENTS IN WIRELESS TELEGRAPHY".

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS IN PHYSICS

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FREQUENCY MEASUREMENTS IN WIRELESS TELEGRAPHY.

INTRODUCTION.

When Mr. Marconi announced in 1896 the successful operation of a practical wireless telegraph, a wide field of investigation of great possibilities was opened to scientific men; and the result is that after a period of only fifteen years there are now in existence hundreds of efficient stations in daily use. Developments have been made along various lines, the greatest progress having been made in the past in the development of sensitive detectors, and in the methods of securing selective transmission and receipt of signals. At present investigators are working upon the problem of securing greater efficiency of the transmitting apparatus for a given amount of power supplied by the generators in order to obtain a greater range of transmission with a smaller consumption of energy than at present. Selective, or syntonic, telegraphy depends upon the use of different wave-lengths by different stations, and since wave-length depends upon the frequency of the oscillations, the question of frequency is of great importance. It is the purpose of this thesis to discuss the principles involved in syntonic telegraphy, and to describe in detail some of the instruments which are used in the measurement of wave-lengths. Special attention will be given to the Fleming cymometer and its use, since one of these instruments has been available in the Physics department.

FUNDAMENTAL PRINCIPLES.

Electric wave telegraphy owes its existence to the discovery of the fact that the discharge of a Leyden jar through a circuit

of low resistance having inductance is not uni-directional, but oscillatory. In 1824 Savary$_1$ observed that when a Leyden jar was discharged through a coil of wire so as to magnetize a steel needle placed within the coil, the needle was sometimes magnetized in one direction and sometimes in the opposite direction, although the inner coating of the jar was charged each time with electricity of the same sign and the connections to the coil were unchanged. The first explanation of this phenomenon was given by Joseph Henry$_2$ in 1842. His explanation was that the charge oscillated from one coating of the jar to the other with decreasing amplitude at each oscillation, the last discharge of sufficient strength to reverse the magnetization of the needle determining the direction of its magnetization.

The first experimental demonstration of this phenomenon was made by Feddersen$_3$ in 1857. By using a rotating concave mirror to project the image of the spark upon a photographic plate, he obtained a photograph that resembled a series of bright dots instead of a single bright line. The series of points representing one end of the spark was made up of alternate brighter and darker spots, the brighter spot at one end having a darker spot at the other end, and vice versa. The explanation of this fact was that the particles torn from the positive electrode were incandescent while those from the negative electrode were not, so that the positive end of the spark is brighter than the negative end. This experiment proved that the discharge is not uni-directional but oscillatory. Feddersen also showed that with high approximation the period of oscillation was proportional to the square root of the capacity and to the square root of the induct-

ance, but did not go further than this point as he did not know the capacity of his Leyden jars.

Previous to Feddersen's experimental verification of this phenomena Lord Kelvin$_4$ had given a mathematical proof of the same in a paper read at Glasgow in 1853. He applied the principle of the conservation of energy to the discharge of a condenser through an inductance, and proved that the time period of this oscillatory is equal to $T = 2\pi\sqrt{LC}$ where L is the inductance and C the capacity of the circuit, provided the resistance is so small that it may be neglected in comparison. The value of the current in the condenser circuit at any instant is expressed by the equation — $i = I e^{-\alpha t} \sin pt$, and that for the potential difference between the condenser plates by the equation — $v = V e^{-\alpha t} \cos pt$, where I represents the maximum value of the current, V the initial maximum value of the potential difference, α is equal to $\frac{R}{2L}$, e is the base of the Naperian system of logarithms, and p is 2π times the frequency n. The value of n is given by the expression —

$$n = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}\ .$$

The period is the reciprocal of the frequency, hence if we neglect the value of R since it is negligibly small in practice, we get the expression — $T = 2\pi\sqrt{LC}$, which is the fundamental formula of wireless telegraphy.

The above equations for i and v when plotted give curves of the form of figures 1 and 2. A comparison of these curves will show that they are displaced from each other by a quarter-phase, a condition which can be readily understood since the current is zero at the instant the potential difference between the condenser plates is a maximum, and vice versa. The exponential term in

each equation shows that the amplitude of the oscillations dies

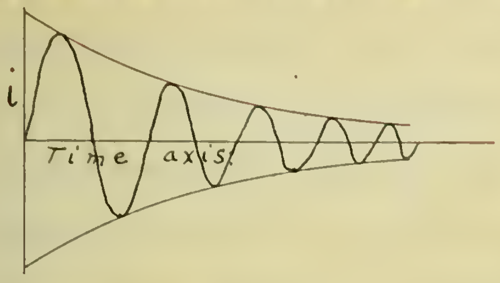


Fig. 1.

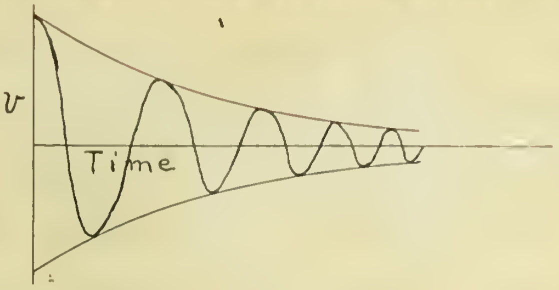
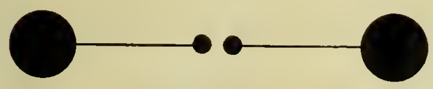


Fig. 2.

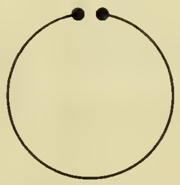
away in accordance with an exponential law, this damping as it is called being due to the heating of the circuit and other energy losses due to radiation and to brush discharge from the condenser plates. Dr. J. Zenneck[5] has shown that in condenser circuits containing a spark gap the damping increases as the current decreases, since the resistance of the gap varies inversely as the current, and the locus of the maxima of the curves approaches a straight line.

In 1865, James Clerk Maxwell[6], having observed the value of a certain constant in the transformation from the electrostatic to the electromagnetic system of electrical units, predicted in connection with his electromagnetic theory of light that electrical energy is propagated with the velocity of light in the form of electromagnetic waves. This prediction was not confirmed by experiment until Hertz[7] made his startling discoveries in 1887 to 1889. Hertz used a simple oscillator of the form of figure 3,



Oscillator.

Fig. 3.



Resonator.

Fig. 4.

consisting of two large metallic spheres about 35 cm. in diameter

connected by two thin rods 60 cm. long except for a short spark gap in the center. As a detector he used a loop of heavy copper wire containing a micrometer spark gap (Fig. 4). When the plane of the resonator was in the same plane as the oscillator a sparking was noticed at the gap in the resonator. A certain size of resonator appeared to respond more strongly than others, due as he thought to the fact that the oscillator and resonator were in tune with each other. It was later shown by Bjerknes[8] that the oscillations of a Hertz oscillator are very strongly damped (Fig. 5) and that Hertz' observations were due to a forced oscillation set up in the resonator by impact as it were. By using a simple rod oscillator of small dimensions (Fig. 6), Hertz[9] obtained waves 66 cm. long, and was able to show that electric waves are polarized in the plane of the oscillator, that they can be reflected by means of a metallic screen and refracted by a prism of pitch or other insulating material, and in fact that they possess very nearly all the properties of the shorter transverse light waves. He obtained a standing wave by reflection, and by measuring the length of the wave and calculating the period of his oscillator, obtained a value for the velocity of the wave which agreed quite closely with those given for the velocity of light. In 1895 Trowbridge and Duane[10] confirmed Hertz' results in an extensive set of experiments, and demonstrated conclusively that electric waves travel with the velocity of light.

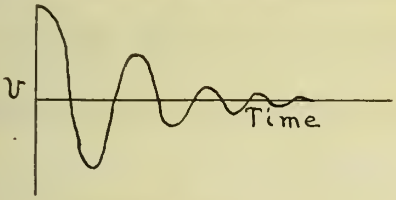


Fig. 5.

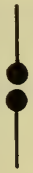


Fig. 6

After Hertz' death, his work was continued by many investigators, but the first systematic attempts to put his discoveries to practical use were made by Marconi, who was then a pupil of

Righi, one of the most active investigators in the field of electric waves. Marconi's first experiments were performed with the simple rod oscillator of Hertz placed vertically with the lower rod earthed (Fig. 7). As this oscillator had a very short wave-length, he placed it in the focal line of a metallic reflector in the form of a parabolic cylinder by means of which he could direct the waves in any desired direction. Since the wave-length and hence the period of the oscillator is very small, it can be seen by an inspection of the Thomson formula that the capacity of the oscillator is very small. Since the energy in a circuit is proportional to the capacity for any given voltage, ($E = \frac{1}{2} CV^2$), the amount of energy used in this oscillator was not sufficient to transmit signals far enough to render the apparatus practical. For this reason the reflectors were discarded and the dimensions of the oscillator increased so that more energy could be used and the distance of transmission correspondingly increased. In connection with Prof. Fleming and others, Mr. Marconi improved his apparatus so rapidly that in 1902 he had established communication across the Atlantic. This was only six years after he had made his first demonstrations of transmission over distances greater than two or three miles.

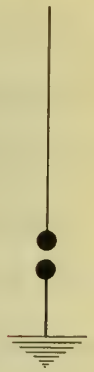


Fig. 7

The question of the wave-length of the simple rod oscillator (Fig. 8) has been worked out by several investigators with varying results. Abraham[11] asserts that the wave-length of an oscil-

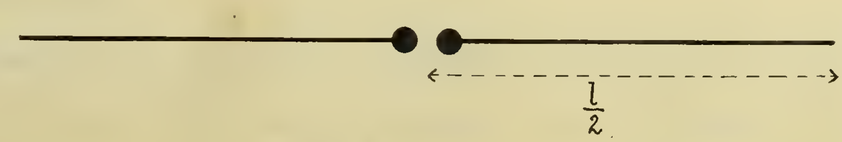


Fig. 8

lator is four times its half-length, while others have obtained results somewhat higher. For a range of 4.2 to 13.4 meters, Conrad[12] obtained for the ratio of the wave-length to the half-length of the oscillator the value 4.24, while Webb and Woodman[13] obtained the value 4.8 where the wave-length varied from 5 to 20 meters. Prof. Pierce[14] obtained the value 4.19 for a range of 16.7 to 63 meters wave-length. By a comparison of the results it would seem that the ratio approaches the value 4 as the length of the oscillator is increased. This may be explained on the ground that the effect of the capacity introduced by the spark gap decreases as the capacity of the remainder of the oscillator is increased. We may conclude from the above that the wave-length of a single vertical wire antenna is very approximately four times its own length. The ratio will be slightly larger than four, since the portion of the wire near the earth has a slightly greater capacity than the upper portion. For a multiple-wire antenna consisting of from two to six wires separated by a distance one fiftieth their length, the wave-length is roughly five times the length of the antenna. This value cannot be pre-determined, but must be obtained by measurement. A capacity plate at the top of an antenna, also a coil connected in series in the antenna, increases its wave-length. However, connecting a capacity in series will decrease its wave-length, since the capacity has the effect of a spark gap in that it divides the antenna into two oscillators[15].

COUPLED CIRCUITS.

The idea of "coupling" a closed oscillation circuit either directly or indirectly to an antenna circuit seems to have occur-

red[16] to Marconi and Prof. Oliver Lodge in England, and to Prof. Ferdinand Braun in Germany about the same time. Direct coupling (Fig. 9) is the connection of two circuits through an inductance

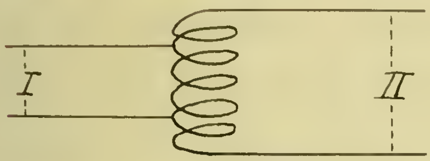


Fig. 9.

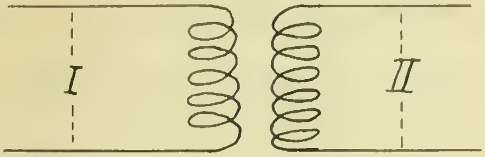


Fig. 10.

in such a way that a part of the inductance is common to both circuits. Indirect coupling (Fig. 10) is commonly known as inductive, or loose, coupling, and is effected by placing the inductances of two circuits so that they act inductively upon each other. The most common method employed for inductive coupling is to use two coaxial coils differing in diameter and insulated from each other. The lines of electric force in one coil thread through the other coil and produce an electromotive force in it by induction.

Prof. Lodge obtained a patent in England in May 1897 and in the United States in Feb. 1898 for a tramsmitting and receiving apparatus for wireless telegraphy, the connections for which are shown in figures 11, 12, and 13. The connections for the sending station (Fig. 11) were arranged in this manner "to allow freer vibrations electrically of the antenna". C_1 and C_2 represent Leyden jars connected in "cascade" through the spark gaps G, g_1, g_2, and g_3, and the inductance coils L_1 and L_2. The coil f was placed between the outer coatings of the jars in order to allow the

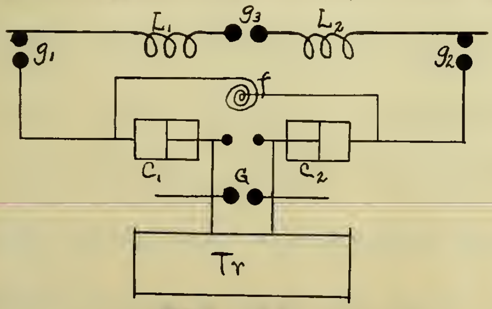


Fig. 11.

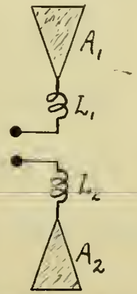


Fig. 12.

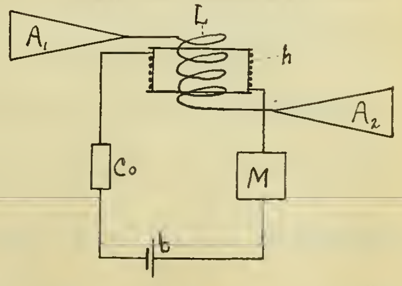


Fig. 13.

jars to become charged by the induction coil or transformer Tr. The inductance of f, and also its resistance, was quite large, so that the discharge would take place through the four spark gaps and not through f. This arrangement is a case of imperfect coupling, and had little advantage over the simple Marconi sender on account of the presence of the spark gap in the antenna itself. Figure 12 shows Lodge's antenna. It consisted of two conical capacity areas A_1 and $A_2$with the inductances L_1 and L_2 between the areas and the spark gap. This form of antenna preserved the symmetrical form of oscillator used by Hertz, with the addition of the inductances, which were to be used to tune the sending and receiving circuits to resonance. Lodge was the first to make use of these syntonizing coils, and in this respect his transmitting system was a distinct advance. In his receiving system (Fig. 13) he placed an inductance L in series with the cpapcity areas A_1 and A_2, and constructed a secondary circuit consisting of the coherer Co, battery b, and telegraph instrument M, connected in series with the coil h, which formed the secondary circuit of an oscillation transformer having the coil L as a primary circuit. This form of receiver was defective in that there was no condenser in the secondary circuit and the oscillations had to pass through the coils of the telegraph instrument, the choking effect of which greatly diminished their intensity. However, it was of value in that it suggested the use of a transformer in receiving. Late in 1897 Lodge and Muirhead modified the receiver by placing an inductance and a capacity in series with the capacity areas, bridging the coherer across the inductance and capacity, and the battery and telegraph instrument across the condenser, the whole arrangement being a special case of direct coupling (Fig. 14). Lodge's

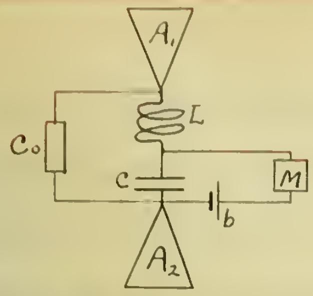


Fig. 14.

form of antenna was very cumbersome in comparison with other systems, however, and his system did not come into practical use.

In October 1898 Prof. Braun patented methods of coupling a Leyden jar circuit to an antenna circuit in order to bring greater quantities of energy into action "since there is a certain active spark length which cannot be exceeded, and the gain in energy cannot be obtained if the spark gap is in the antenna circuit direct". He also stated that slower oscillations had the advantage that their energy may be increased by increasing the potential amplitude by means of transformers, and by an increase of capacity, and the use of more powerful generators of electricity. Braun lost whatever advantage he had gained by his coupled circuits since he did not provide for the tuning of the primary and secondary circuits to resonance. Figures 15a, b, and c show different forms of coupling adopted by Prof. Braun. Figures 15a and b are forms of direct coupling, where the Leyden jar is common to both circuits, its use in the secondary circuit being to take the place of a ground connection. Fig. 15c is the case of inductive coupling, where the primary circuit acts inductivley upon the secondary, which is connected at its upper end to the aerial wire and at its lower end to a balancing capacity or ground connection. In the system of wireless telegraphy which bears his name, Prof. Braun has adhered to the

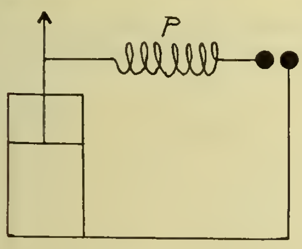


Fig. 15a.

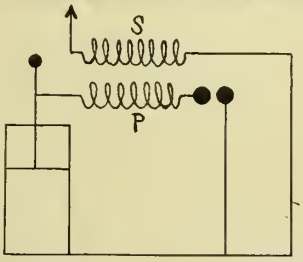


Fig. 15b.

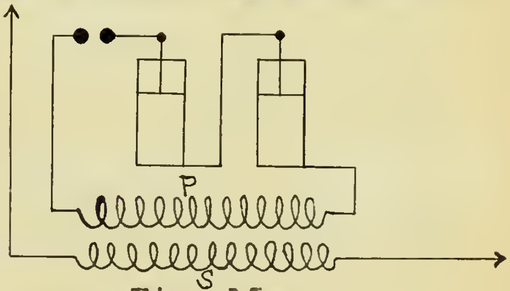


Fig. 15c.

use of the balancing capacity instead of the ground connection. Nothing was said in the patent specifications about receiving circuits, attention being paid only to arrangements for using more energy in the transmitter.

In 1900 Marconi patented the connections for an inductively coupled sending station, and had already patented connections for a transformer arrangement in the receiving circuit. He stated that the advantage of the coupled circuit lay in the fact that a closed circuit is a good conserver, and an open circuit a good radiator of energy. He was led to the adoption of the coupled receiving circuit by the fact that his earlier form of receiving circuit would respond to and register false signals when acted upon by any strong electromagnetic impulse, and was susceptible to atmospheric disturbances. By means of the transformer arrangement the stray impulses and waves could be excluded. The connections for his inductively coupled receiving circuit are shown in figure 16. P represents the primary coil in series with the antenna and the ground connection. Oscillations in P produce oscillations in the secondary coil S, which is connected in series with a capacity C and the coherer Co. When oscillations occur in this secondary circuit the coherer is rendered conducting, and the current flows through the tertiary circuit composed of the coherer, the coils k and k', and the Morse writer M. The coils k and k' are choke coils which prevent the oscillations from passing through

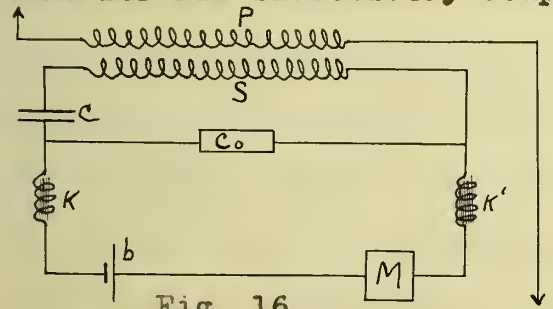


Fig. 16.

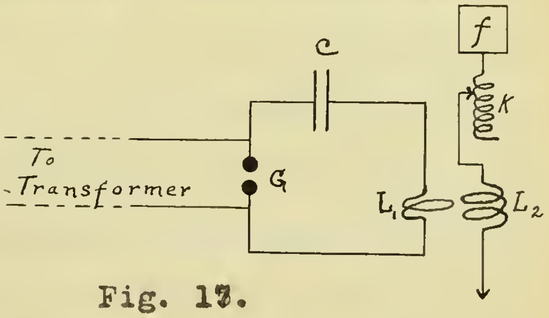


Fig. 17.

the telegraph instrument.

The sending circuit is shown in figure 17. The antenna circuit consists of the capacity area f in series with a variable inductance k, the secondary coil L_2 of the sending transformer, and the ground. The primary circuit sonsists of the spark gap G in series with a condenser C and the primary L_1 of the sending transformer. Marconi was the first to mention the necessity of tuning both primary circuits and secondary circuits in the sending and receiving station to resonance, and to provide for the same in his apparatus, hence his work was a decided advance over that of the other investigators in the field.

One of the chief advantages of the coupled circuit in the receiving apparatus is that it eliminates the high resistance detector from the antenna circuit and permits much sharper tuning to the incoming wave. Prof. Pierce$_{17}$ shows an interesting set of curves illustrating the effect of resistance upon the sharpness of resonance. On account of the presence of the detector in the closed circuit of the receiver, this circuit is not a sharply tuned circuit. This, however, is of minor importance, as the sharp tuning of the antenna circuit excludes undesired waves, and the tuning of the closed circuit merely intensifies the signals, so that a distant station may be heard more distinctly.

RESONANCE.

As was suggested in the preceding sections, syntonic, or "tuned", systems are made use of in order that the receiving operator may exclude all signals other than those which he wishes to receive. Where the receiving station is within the range of two or more sending stations, the ability to do this effectively is

absolutely essential, as the confusion of signals that otherwise would result would render all the signals unintelligible. The tuning of a receiving station consists in varying the inductance or capacity of the antenna circuit, and also of the secondary circuit, until the intensity of the incoming signals is a maximum. When this condition exists, the receiving circuits are said to be in resonance with each other and with the sending station.

The principle of resonance has applications in mechanics and sound, as well as in electricity, and may be clearly illustrated by analogies taken from these two branches of physics. Two tuning forks having the same pitch — i.e., the same number of vibrations per second — are placed a short distance apart in a room. If one of the forks be made to vibrate for a time, the second fork will be found to vibrate also. If the distance is not too great and the vibrations of the first fork are of sufficient intensity, those of the second fork will produce an audible sound. This phenomenon is due to the fact that the sound waves striking the second fork have the same time period of vibration as the fork, the energy communicated to the fork by them causing it to vibrate with its own free period of vibration. This is the condition called resonance, and the two forks are said to be in resonance with each other.

A common lecture experiment in physics is known as the Lodge experiment, and illustrates in a simple manner the principle of electrical resonance. The apparatus (Fig. 18) consists of two Leyden jar circuits A and B, placed about a meter apart with their planes parallel to each other. Circuit A is a fixed circuit consisting of a Leyden jar, the two coatings of which are connected by a rectangular wire frame except for the spark gap a. Circuit

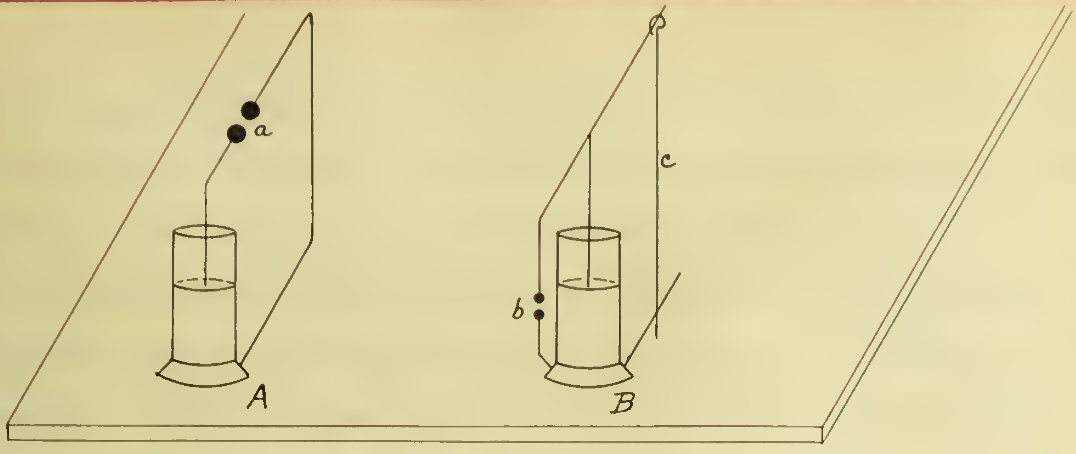


Fig. 18.

B is similar to A except that the side c of the rectangle may be shifted from one position to another along the horizontal portion of the circuit, changing the dimensions of the rectangle and hence the inductance of the circuit. The two Leyden jars have approximately the same capacity, as their dimensions are practically the same. When the Leyden jar in circuit A is charged by means of a static machine or induction coil so that a succession of discharges passes across the gap a, a position of c will be found along the rectangle where a maximum sparking will occur at the gap b. As the rod c is moved away from this position in either direction, the sparking at b will decrease in intensity and will finally cease. For the position of c at which the maximum sparking occurs, the inductance of the two circuits is the same, hence the periods of oscillation are equal and we have the condition of resonance. The circuit B could also be arranged so that the rectangle would be fixed, and the capacity varied. In either case we have a simple illustration of the method of tuning two wireless antennae to resonance.

The quantitative study of resonance phenomena was taken up at the suggestion of Prof. Hertz by a pupil of his, V. Bjerknes, who reported$_{18}$ his results in an article which appeared in 1895 and has become one of the classics of the subject. Drude$_{19}$,

Overbeck[20], Pierce[21], and others have also made extensive experimental investigations of resonance phenomena in coupled circuits similar to those used in wireless telegraphy.

In discussing this question of resonance, let us first consider the case in which a condenser connected in series with an inductance is acted upon by a simple harmonic electromotive force such as is supplied by an induction coil or transformer[22]. Writing the differential equation for the current in the condenser circuit we get the expression —

$$L\frac{di}{dt} + Ri + v = E \sin qt,$$

where $L\frac{di}{dt}$ represents the electromotive force of self-induction, Ri the drop of potential around the circuit, v the potential difference between the condenser plates, and E sin qt the applied electromotive force where q is equal to 2π times the frequency n_1 of the generator. The current i is equal to $C\frac{dv}{dt}$, hence by substitution the above equation becomes —

$$LC\frac{d^2v}{dt^2} + CR\frac{dv}{dt} + v = E \sin qt,$$

which may be written in the form —

$$\frac{d^2v}{dt^2} + \frac{R}{L}\frac{dv}{dt} + \frac{1}{LC}v = \frac{E}{LC}\sin qt.$$

The solution of this equation gives the following expression —

$$v = V\sin(qt - \varphi) + V' e^{-\alpha t}\sin(pt - \theta),$$

which indicates that the current consists of two superimposed oscillations. The first term of the second member of the equation indicates the presence of a forced oscillation of amplitude V and the frequency n_1 of the impressed electromotive force. The second term indicates a second oscillation of amplitude V' and the frequency n_2 of the condenser circuit, since p is equal to 2π times the frequency n_2. The presence of the exponential term in-

dicates that this second oscillation, called the free oscillation, is damped and dies out after a short time. In this particular case, the electromotive force of the impressed wave simply keeps up the charging of the condenser so that sparks will pass and oscillations take place in the circuit, since no oscillations are present in a third circuit coupled to the condenser circuit, as for instance an antenna circuit, when sparks are not passing on account of the very low value of the impressed frequency. By further treatment of the equation for v, it may be shown that the current in the secondary circuit has its maximum value when the frequencies n_1 and n_2 are equal. This condition is realized when the impressed electromotive force is supplied from a primary circuit coupled inductively with the secondary (Fig. 19) where the two natural frequencies are of the same order of magnitude.

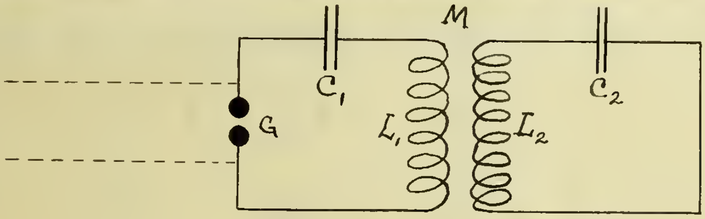


Fig. 19.

Two pendulums coupled together as in Fig. 20 furnish the mechanical analogy of this phenomenon. The upper pendulum is fastened to a rigid support and has a very long suspension and a heavy bob. The lower pendulum is fastened to the bob of the other, and has a very short suspension. The upper corresponds to the driving, or inducing, circuit and the lower to the driven, or induced, circuit. When the upper pendulum vibrates, the lower one will also vibrate, each with its own period as though independent of the other. This corresponds to the case

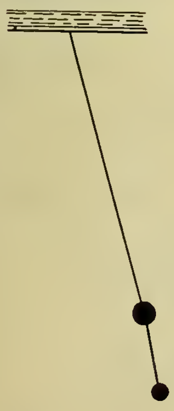


Fig. 20.

of the condenser circuit which is charged by an alternating current transformer. Now if the two pendulums are made the same length so that their periods of vibration are equal, a maximum amplitude of oscillation will result, but the system will have two periods of vibration which are different from the natural periods of the two pendulums alone. The weight of the lower pendulum tends to lengthen the period of the upper one, and the motion of the upper one tends to shorten the period of the lower one. The following paragraph will show how this analogy applies to the two coupled circuits of Fig. 19.

Let i_1 and v_1 , and i_2 and v_2 , respectively, be the current and the potential difference between the condenser plates of the primary and secondary circuits. Following the line of Overbeck's investigation, and using the English notation$_{23}$, the differential equations for the currents i_1 and i_2 may be written ——

$$L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} + R_1 i_1 - v_1 = 0$$

$$L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} + R_2 i_2 - v_2 = 0$$

where the new term $M \frac{di_2}{dt}$ is the electromotive force induced in the primary circuit by the current in the secondary due to the mutual inductance of the two circuits, and $M \frac{di_1}{dt}$ represents the corresponding electromotive force in the secondary due to the current in the primary. Substituting the values of i_1 and i_2 in these equations, they take the following form ——

$$C_1 L_1 \frac{d^2 v_1}{dt^2} + C_1 R_1 \frac{dv_1}{dt} + C_1 M \frac{d^2 v_2}{dt^2} + v_1 = 0$$

$$C_2 L_2 \frac{d^2 v_2}{dt^2} + C_2 R_2 \frac{dv_2}{dt} + C_2 M \frac{d^2 v_1}{dt^2} + v_2 = 0$$

By a long process of differentiation, elimination, and substitution, a solution of these equations is obtained which expresses the period T of the oscillations in each circuit. This solution is —

$$T^2 = \frac{T_1^2 + T_2^2 \pm \sqrt{(T_1^2 - T_2^2)^2 + 4\,k^2\,T_1^2\,T_2^2}}{2}$$

or

$$T' = \sqrt{\frac{T_1^2 + T_2^2 + \sqrt{(T_1^2 - T_2^2)^2 + 4\,k^2\,T_1^2\,T_2^2}}{2}}$$

$$T'' = \sqrt{\frac{T_1^2 + T_2^2 - \sqrt{(T_1^2 - T_2^2)^2 + 4\,k^2\,T_1^2\,T_2^2}}{2}}$$

where T_1 is the natural period of the primary alone, T_2 the natural period of the secondary alone, and k^2 is the ratio $\frac{M}{L_1L_2}$, k being defined as the coefficient of coupling. When the primary and secondary circuits are in resonance, T_1 is equal to T_2, and the equations for T' and T'' reduce to —

$$T' = T_1\sqrt{1 + k} \qquad\qquad T' = T_2\sqrt{1 + k}$$
$$\text{or,}$$
$$T'' = T_1\sqrt{1 - k} \qquad\qquad T'' = T_2\sqrt{1 - k}$$

Writing these equations in terms of the frequency and of the wave-length, we have —

$$n' = \frac{n_1}{\sqrt{1 + k}} \qquad\qquad \lambda' = \lambda_1\sqrt{1 + k}$$
$$\text{and}$$
$$n'' = \frac{n_1}{\sqrt{1 - k}} \qquad\qquad \lambda'' = \lambda_1\sqrt{1 - k}$$

Solving for k in each case, we get —

$$k = \frac{T'^2 - T''^2}{T''^2 + T'^2} = \frac{n''^2 - n'^2}{n'^2 + n''^2} = \frac{\lambda'^2 - \lambda''^2}{\lambda''^2 + \lambda'^2}$$

If the two circuits are in resonance, but far apart so that k is very small, T' approaches T''. As k increases the values of T'

and T" differ more widely, and in the special case where k is unity $T' = \sqrt{T_1^2 + T_2^2}$ and T" is zero.

Bjerknes' treatment of the subject takes up the case in which the electromotive force impressed upon the secondary circuit is itself a damped oscillation in accordance with Lord Kelvin's theory of oscillatory discharge. Writing his differential equation in the English notation, we have —

$$\frac{d^2v}{dt^2} + \frac{R_2}{L_2}\frac{dv}{dt} + \frac{1}{C_2L_2}v = \frac{E}{C_2L_2}e^{-\alpha_1 t}\sin(p_1t + \phi)$$

where $\frac{R_2}{2L_2}$ is the damping factor α_2, $\frac{1}{C_2L_2}$ the value $(p_2^2 + \alpha_2^2)$, p_2 is equal to 2π times the frequency n_2 of the secondary circuit, and α_1 is the damping factor and p_1 is 2π times the frequency n_1 of the primary circuit. The initial conditions are that t, v, and $\frac{dv}{dt}$ are all equal to zero; i.e., that the system is in equilibrium. The disturbance of the equilibrium of the secondary circuit arises from the force represented by the right hand member of the equation, by which the waves in the primary act upon the secondary circuit. The solution of this differential equation gives an integral expression which is the sum of two particular integrals —

$$v = v_a - v_b$$
$$v_a = e^{-\alpha_1 t}(A_1 \sin p_1t + A_2 \cos p_2t)$$
$$v_b = e^{-\alpha_2 t}(B_1 \sin p_2t + B_2 \cos p_2t)$$

Physically, this result indicates the presence of a forced oscillation having the same frequency and damping factor as the primary circuit superimposed upon a free natural oscillation having the same frequency and damping factor as the secondary circuit. The total integral may be written in the form —

$$v = M \sin(mt + m'),$$

which represents the motion of the electricity in the secondary circuit as a single oscillation, where the amplitude M and the phase angle m' are both complicated functions of the time t. The quantity M also contains the exponential terms which determine the rate of decay of the oscillation.

By drawing the amplitude curves $y = \pm M$, Bjerknes has shown that v represents a wave curve enclosed between the positive and negative amplitude curves. When the damping and frequency of the two circuits are equal, the curve takes the form of Fig. 21. If both circuits have the same period but different damping, the curve takes the form of Fig. 22, which differs but little from Fig. 21. This case applies particularly to two practical wireless circuits in resonance, since owing to differences in construction the damping will not as a rule be equal. Where the two frequencies also differ, the curve is a damped sine wave (Fig. 23). This is the phenomenon known in acoustics as beats.

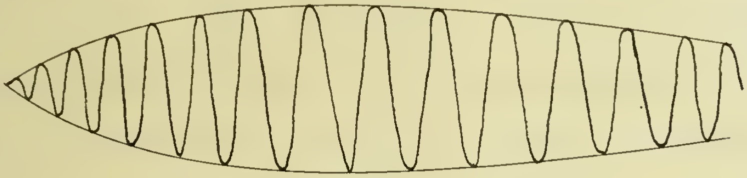


Fig. 21.

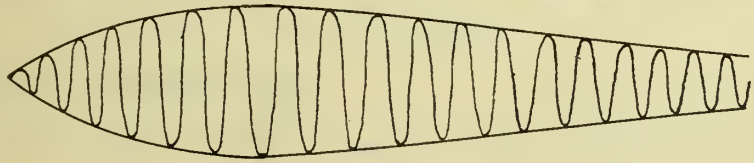


Fig. 22.

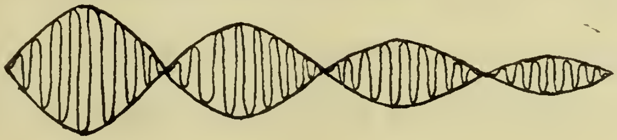


Fig. 23.

WAVE METERS.

In practice it is very desirable to have a means of quickly determining the wave-lengths of the antenna and the closed circuit in order that they may be adjusted to resonance and the maximum intensity of the oscillations in the antenna obtained. These determinations are of special importance when a station is being installed and it is desired to obtain a certain sending wave-length for the station. This means is supplied by the use of calibrated resonance circuits so constructed as to be portable and easy to manipulate. These calibrated circuits are called frequency meters or wave meters. The instruments used for this purpose by the different companies differ only in the manner of varying the dimensions of the circuit in order to obtain resonance with the oscillating circuit, and in the form of indicator used to show when the condition of resonance exists. In most cases they are closed circuits. Three types of wave meter have been chosen for discussion because of their simplicity of construction and operation. Before proceeding with the discussion of these instruments, the methods of calibration will be considered.

Methods of Calibration.

Since the construction of the commercial form of instrument generally does not permit the accurate calculation of its capacity and inductance, its calibration is effected by tuning it to resonance with circuits of known wave-length for different positions of the scale of the variable factor of the instrument. The wave-lengths of these known circuits are obtained by the use of parallel-wire systems where the wave-length may be measured directly, by constructing the circuit in such a manner that its inductance and capacity may be calculated from its dimensions, and by photo-

graphing the spark in order to obtain the period and from that the wave-length. In the last two instances the wave-length is obtained by the application of Lord Kelvin's formula.

For wave-lengths up to 200 meters, the parallel-wire systems are used, but for greater wave-lengths Dr. Diesselhorst[24] has shown that a systematic error which cannot be neglected enters in. One form of parallel-wire system (Fig. 24) is due to Prof. Lecher.[24]

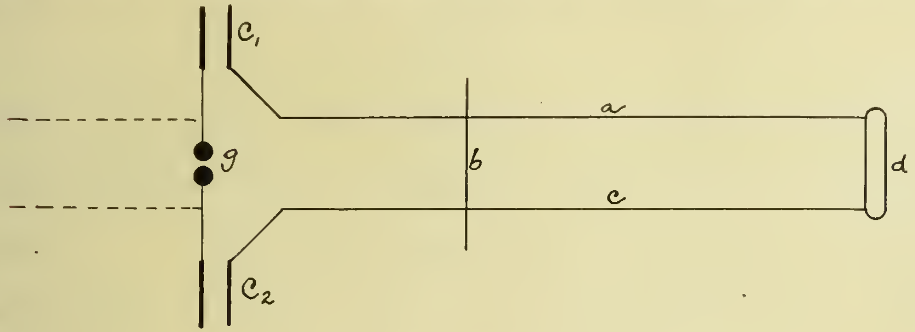


Fig. 24.

It consists of a Hertz oscillator whose end capacities are metal plates about 30 cm. square, opposite which two similar plates are placed to form the air condensers C_1 and C_2. Two wires, a and c, attached to these outer plates are brought parallel to each other and about 10 cm. apart and stretched out for a distance of several meters. Across the ends of the wires, which are insulated from each other, is placed a glass tube d which is pumped out to a sensitive vacuum or filled with rarified carbon dioxide or other gas. A metallic bridge b is placed across the wires, dividing the system into a closed and an open oscillating circuit. When sparks are passing across the gap g, a position of the bridge will be found along the wires for which the two circuits are in resonance and the tube will glow very brightly. For all other positions the glow will be very faint or will disappear entirely. The maximum glow of the tube indicates that there is a maximum difference

of potential between the ends of the wires, and a node or point of zero potential at the bridge. The distance from the end of one wire through the bridge to the end of the other wire is therefore one-half the wave-length, and can be measured directly. Another form of parallel-wire system used is shown in Fig. 25. It differs from the Lecher system in that the wires are extended directly from the spark gap and no bridge is used, the system being a single open circuit. The loop of potential is at the open end of the wires as before, and the node is at the spark gap. The length of one wire to the spark gap is therefore one-fourth the wave-length of the system.

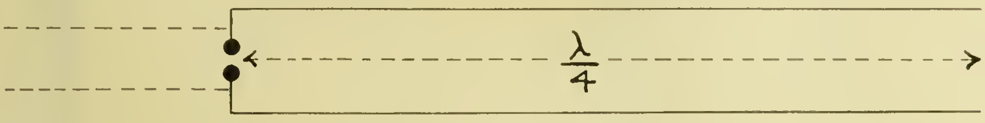


Fig. 25.

For wave-lengths beyond the range of the parallel-wire systems the closed circuits whose inductance and capacity can be calculated are made use of. The photographic method, because of mechanical limitations, is used only in the determination of the longer wave-lengths, which have long periods of vibration.

Slaby's "Multiplication-Staff". (Fig. 26)

This form of wave meter$_{26}$ consists of a long glass or ebonite tube a, upon which is wound a large number of turns of silk-insulated copper wire b, having a diameter of about .2 mm., the diameter of the wire itself being about .1 mm. The free end of the wire at the lower end of the coil is connected to a metallic cylinder c, which serves as a handle for the staff. The free wire at the upper end of the coil is passed through a small hole to the inside of the tube at a distance of about one and one-half centimeters

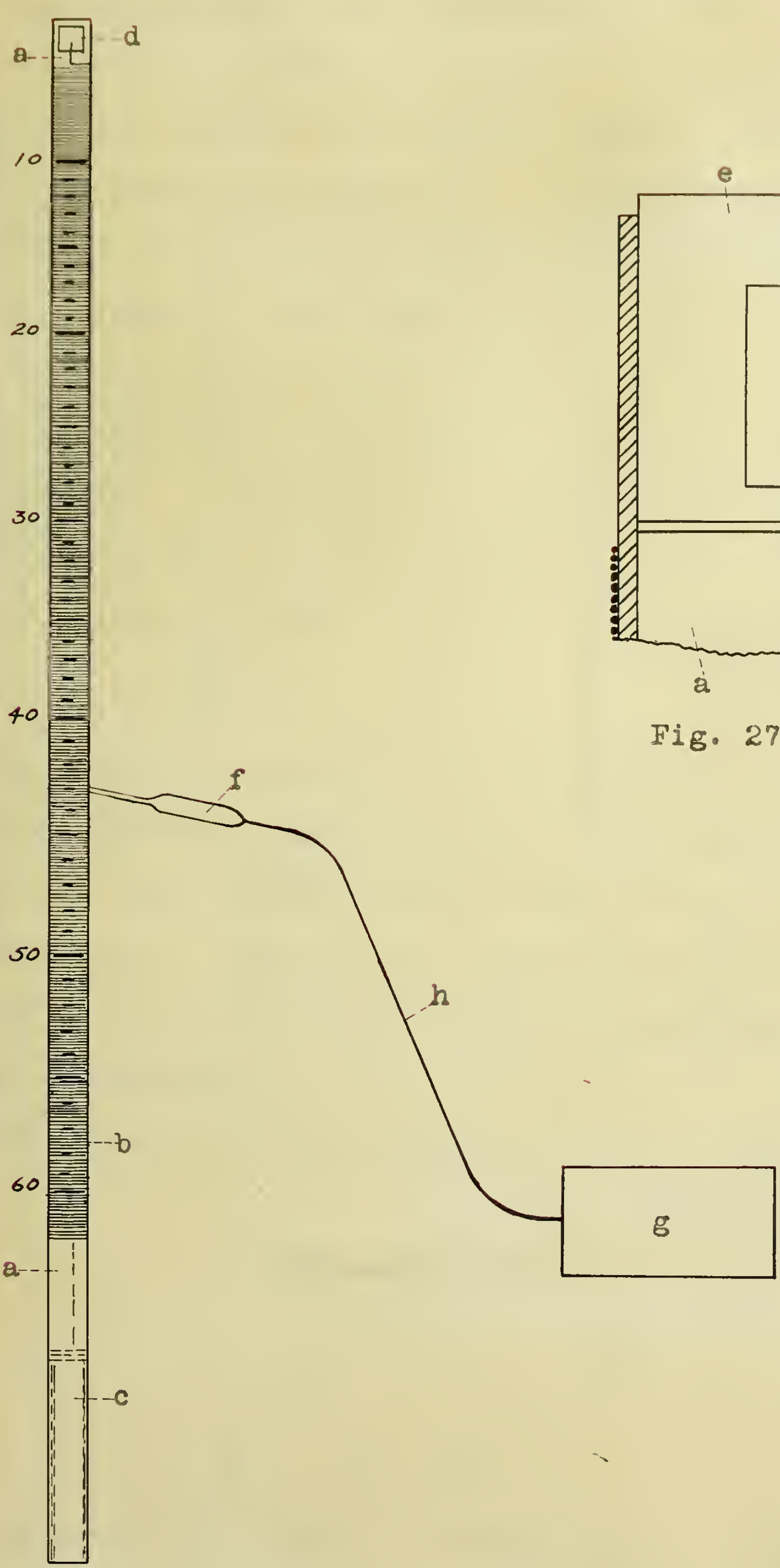


Fig. 26.

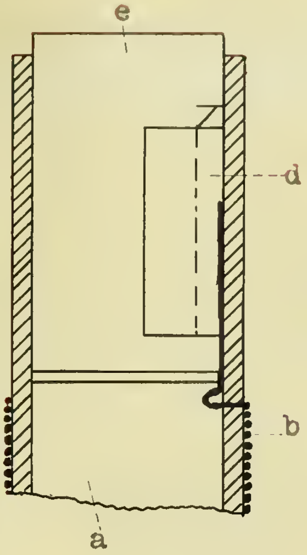


Fig. 27.

from the end, and is held against the glass by a small screen d of barium-platinocyanide paper containing flakes of gold leaf, which is in turn held in place by a plug e. The arrangement at the top of the coil is drawn on an enlarged scale in Fig. 27. The remainder of the apparatus consists of a blunt-pointed metallic conductor f, which is connected to a ground plate g, or to any ground connection, by a flexible conducting wire h. The staff is calibrated so that the wave-length in meters can be read directly from the scale marked on the coil. The range of the staff varies with its length and diameter. Those 80 cm. in length give the following ranges for different diameters of the tube:

Diameter in mm.	Range in meters.
10	25 — 50
20	50 — 100
40	100 — 200

For the wave-lengths used in practice, larger diameters are used, depending upon the range desired. The commercial sets consist of several of these staffs, usually three, with a total range of 120 to 1000 meters. This range is generally sufficient, as wave-lengths greater than 1000 meters are seldom used except in trans-atlantic telegraphy.

The method of using this wave meter is shown in Fig. 28.

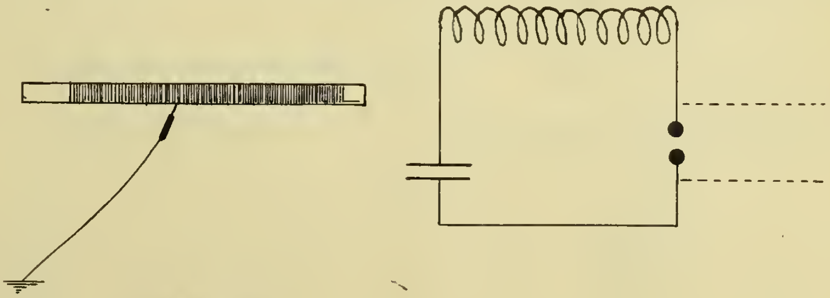


Fig. 28.

The open end of the staff is brought up to a circuit in which oscillations are taking place, preferably that part of the circuit between the condenser and the inductance coil, since that part of

the circuit is subject to the greatest variation of both current and potential. The rod is held by the left hand, and the earthed conductor f is moved along the coil with the right hand until a maximum glow is obtained at the screen. The portion of the coil included between the open end and the conductor f is then in resonance with the oscillating circuit, and the wave-length is read from the scale on the coil.

The advantage of this form of wave meter is its compactness and portability. It has disadvantages, however, which render it inferior to other forms. The capacity of a coil of this kind is very small and is affected by the capacity of neighboring conductors, hence its wave-length will be affected. The readings of the scale are therefore valid only when the instrument is used under the conditions existing when it is calibrated. It also has the disadvantage that it cannot be used for quantitative measurements, as the indicator shows only the condition of resonance.

In the course of the work, the writer constructed a wave meter of this form, using a glass rod 7 mm. in diameter, wound for 84 cm. of its length with No. 36 silk-covered copper wire. As a detector, a small paper screen covered with sodium silicate mixed with willemite powder was used. The coil was calibrated by means of the parallel-wire systems described above. During the process of calibration the coil was kept as far from the oscillating circuit as was possible to do so and still obtain effective readings in

Length of Coil in Cm.	Wave-Length in Meters.
8.7	18.0
13.5	20.5
16.0	24.0
21.5	32.5
37.0	48.0
74.0	94.0
77.0	96.0

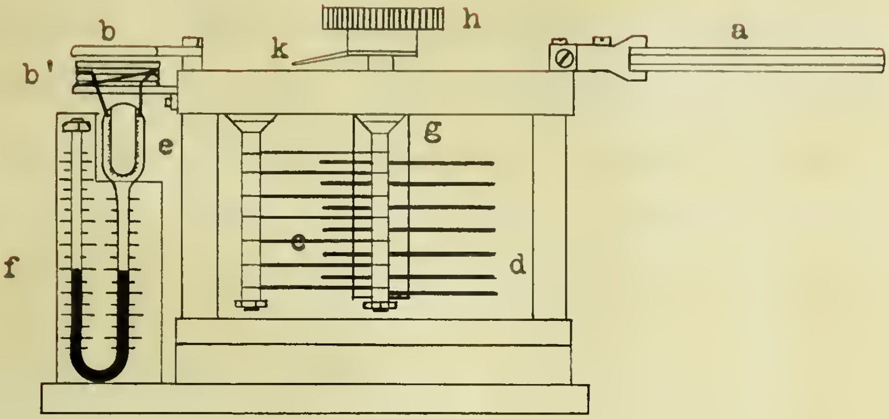


Fig. 29. Elevation.

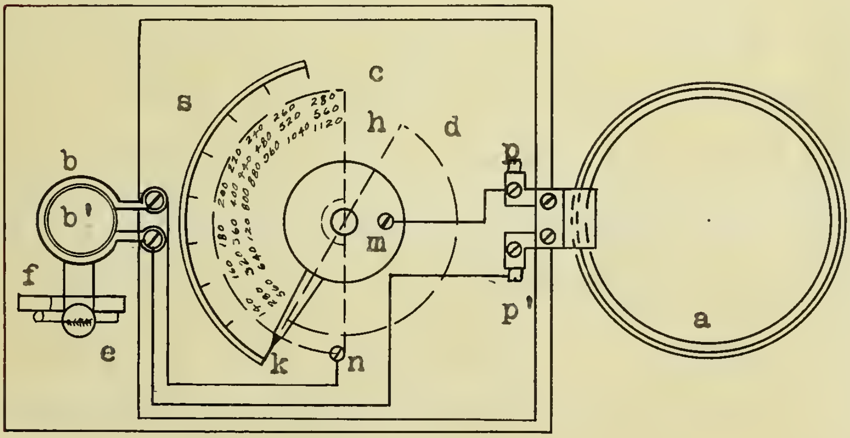


Fig. 30. Plan.

order to reduce the effect of the parallel wires upon its capacity. The readings in the first column of the above table are the mean of several readings taken on the coil for the given wave-length of the oscillator. These results cannot be considered very accurate because there was no sharp resonance effect and the point of contact on the coil for a maximum glow at the screen could not be determined with exactness. This error in locating the point of contact is due to persistence of vision, and can hardly be eliminated.

The Donitz Wave Meter. (Figs. 29 and 30)

The Donitz$_{27}$ wave meter consists of a stationary inductance coil a connected in series with a small coil b and a variable rotary condenser cd to form a closed circuit. Coupled inductively with b is another small coil b' which is connected in series with a fine platinum heating wire e. This "heater" is sealed into the bulb of an air thermometer f. The rotary condenser consists of two sets of semi-circular metal plates parallel to each other with all the plates equally distant. One set c is fixed, and the set d is mounted on a metallic spindle g, by which more or less of the surface of the plates will be made to overlap that of the fixed plates by turning the hard rubber knob h. In this way the capacity of the condenser is varied at will by the operator, the pointer k indicating the degree of rotation of the movable plates. The dimensions of these plates and their distance apart are so chosen that a rotation through 120° from 40° to 160° increases the capacity four times. Since, when the other factors remain constant, the wave-length is proportional to the square root of the capacity, this increase of capacity doubles the wave-length of the instrument. The connection to the movable plates is made at the point

m, and to the fixed plates at the point n. The condenser is immersed in paraffine oil in a glass jar, since the dielectric constant of the oil is greater than that of air, and the leakage by brush discharge or sparking between the oppositely charged plates is prevented. The inductance a consists of several turns of insulated wire in the form of a flat circular coil of rectangular cross-section, connected to the terminals p and p' by plug connectors so that another ring may be substituted if desired. Each wave meter has three or more of these ring inductances whose dimensions are so chosen that the wave-length for a maximum capacity of the condenser with one ring is the same as that for a minimum value of the capacity when the next larger ring is substituted. With a series of these rings, the wave meter may have a wide range of measurement. The scale s is calibrated in wave-lengths and can be read directly.

The instrument is calibrated by calculation. The inductance of the coils is calculated by means of Stefan's formula$_{28}$. The capacity of the condenser for different scale readings is measured by a bridge method, or by the absolute method where an electrically driven tuning fork is used to charge and discharge the condenser. The wave-length is then calculated by application of the Thomson formula.

To use the wave meter, it is brought near the oscillation circuit to be tested, and the capacity of the condenser varied until a maximum reading of the air thermometer is obtained, when the wave meter is in resonance with the oscillating circuit. The distance of the instrument from the other circuit should be chosen so that the coupling will be very loose, otherwise two maxima will appear, due to the reaction of the wave meter circuit upon the oscil-

lating circuit. This statement applies to the case where there is but one wave present in the oscillator. In obtaining the wave-length of an antenna in actual use, two maxima will be found, which is in accordance with the theory previously discussed.

The use of a sensitive hot wire instrument as an indicator makes it possible for quantitative measurements to be obtained. Resonance curves may be plotted by taking the readings of the thermometer as ordinates and the corresponding wave-lengths, or frequencies, as abscissae. From these resonance curves, the damping factors of the circuits may be calculated by Bjerknes' method[29]. The coefficient of coupling of two circuits may be obtained by an application of one of the formulas for k given on page 18. Also small inductances and capacities may be determined by the resonance method, which will be described in connection with the Fleming cymometer.

The use of oil as an insulator is a disadvantage in that the capacity of the condenser increases slightly with increase of frequency. This error is negligible, however, except for very short wave-lengths[24]. The exact construction of the condenser makes this wave meter expensive to manufacture, but this disadvantage is outweighed by its advantages, which are its portability and compactness.

The Fleming Cymometer. (Fig. 31)

The Fleming cymometer[30], as shown in the theoretical diagram of Fig. 32, consists of a variable condenser and a variable inductance connected in series to form a closed circuit. The condenser consists of two concentric brass tubes a a' separated by a thin, close-fitting ebonite tube b, which serves as a dielectric. The

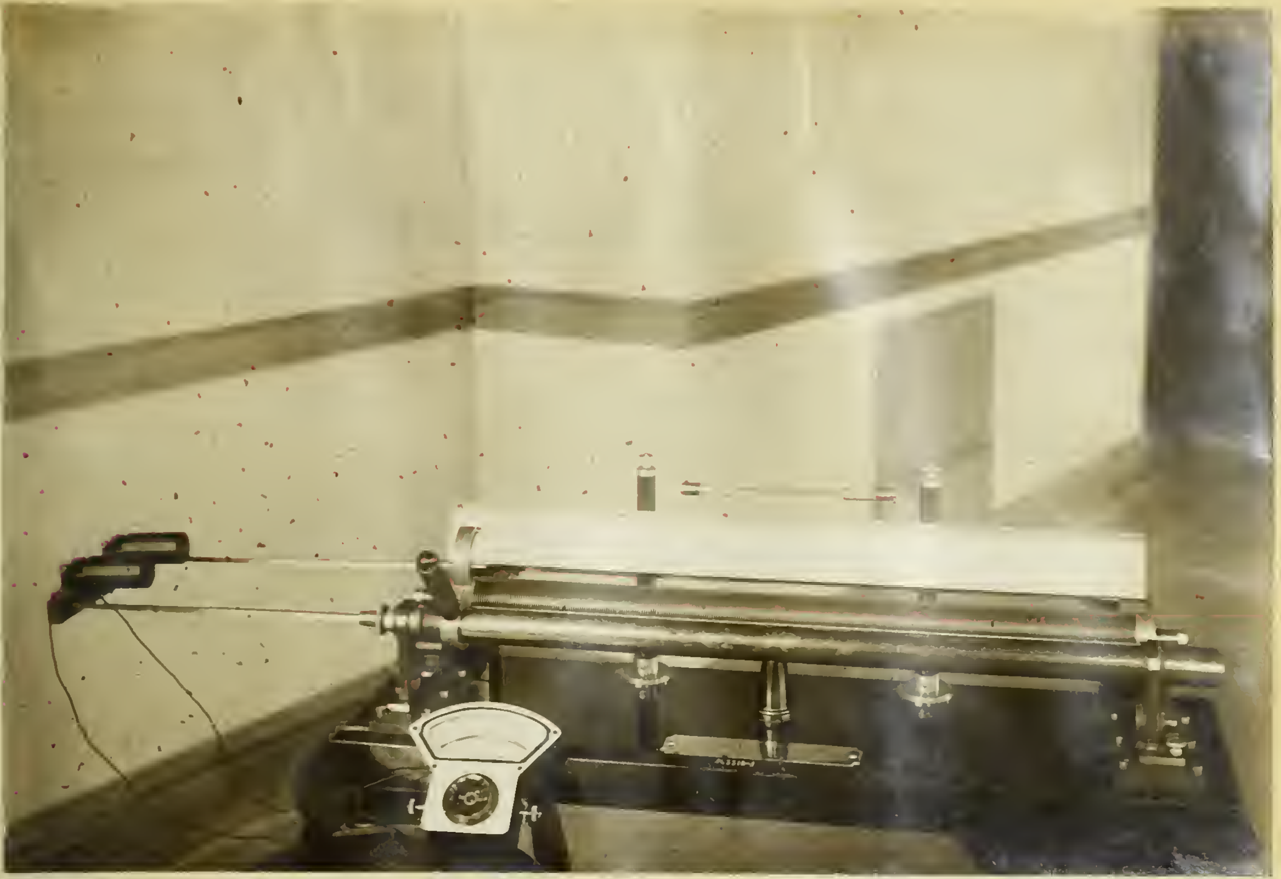


Fig. 31.

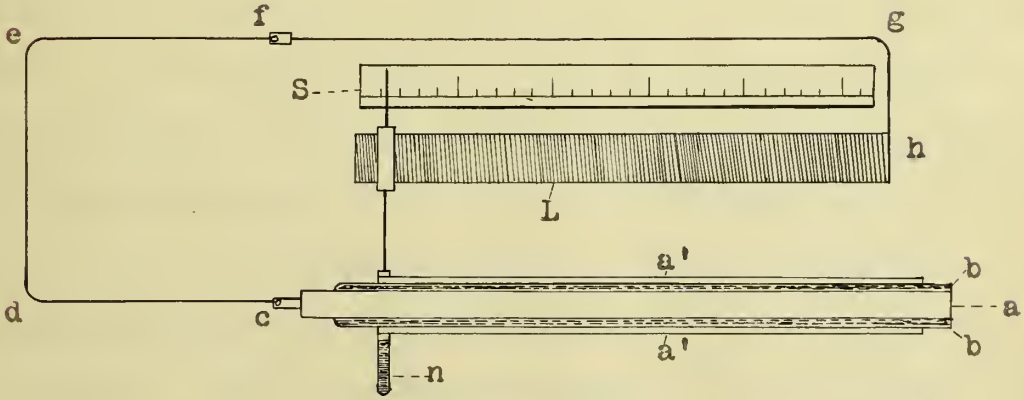


Fig. 32.

inductance L consists of a long coil of bare copper wire wound on an ebonite core. The coil has a single layer of turns spaced about a millimeter apart. One end of this coil is connected with the inner tube of the condenser by a heavy copper bar cdefgh of rectangular cross-section. The circuit is completed by a saddle contact k connected to one end of the outer sliding tube of the condenser by a metallic collar to which is attached an ebonite handle. Moving the handle back and forth with the saddle contact resting upon the inductance coil varies both the inductance and the capacity of the circuit at the same time, and in the same proportion. A glass tube filled with rarified neon gas is connected between the inner and outer tubes of the condenser, and serves as an indicator. The double copper bend may be disconnected at the points c and f, and a special bend (See photograph) inserted which contains two gaps closed by brass straps. For quantitative measurements a fine platinum resistance wire may be inserted in one of these gaps. This resistance wire is in contact with a thermal junction which is connected in series with a sensitive single-pivot galvanometer. The induced currents in the cymometer circuit produce a heating effect in the resistance wire, and this heating effect produces an electromotive force in the thermal junction which causes a deflection of the galvanometer. When the cymometer is adjusted to resonance with a neighboring circuit in which oscillations are present, there is a maximum glow of the neon tube, also a maximum deflection of the galvanometer. The galvanometer is the more sensitive of the two in indicating the position of resonance. The scale S of the instrument is calibrated so that the wave-length in meters and in feet, the frequency per millionth of a second, and the value of the oscillation constant $\sqrt{CL}$ may be read directly

under the pointer attached to the saddle contact. In the expression $\sqrt{CL}$, as used in this instance, L is the inductance of the circuit in centimeters, and C the capacity in microfarads.

The cymometer is calibrated by calculation of the inductance of the coil L, and the measurement of the capacity of the condenser. The inductance of a coil of this type is given by the expression $L = (\pi DN)^2 l$, where D is the diameter of the coil in centimeters, N the number of turns per centimeter length, and l the length of the coil in centimeters. The capacity of the condenser is proportional to the overlapping length of the tubes by reason of a proper choice of its dimensions. For each type of instrument, of which there are four, the dimensions of both the inductance coil and the condenser are so chosen that the inductance and capacity are varied simultaneously in the same ratio. This permits a uniform calibration of the scale in wave-lengths and frequencies, as an inspection of the Thomson formula will show. The scale of oscillation constants is also uniform for the same reason. The capacity and inductance of the connections are disregarded, since they have no appreciable effect$_{24}$.

The four types of cymometer manufactured for commercial use have a total range of wave-lengths from 33 meters to 3000 meters. For laboratory use, and for all ordinary practical purposes, type 1, having a range from 33 meters to 1100 meters, is adapted. With this instrument is furnished a rectangular inductance frame having an inductance of 4000 cm., which is used in the measurement of small capacities, such as Leyden jars, and small inductances.

To measure the capacity of a Leyden jar, the jar is connected in series with the inductance frame and a spark gap (Fig. 33) and oscillations are set up in this circuit by means of a static mach-

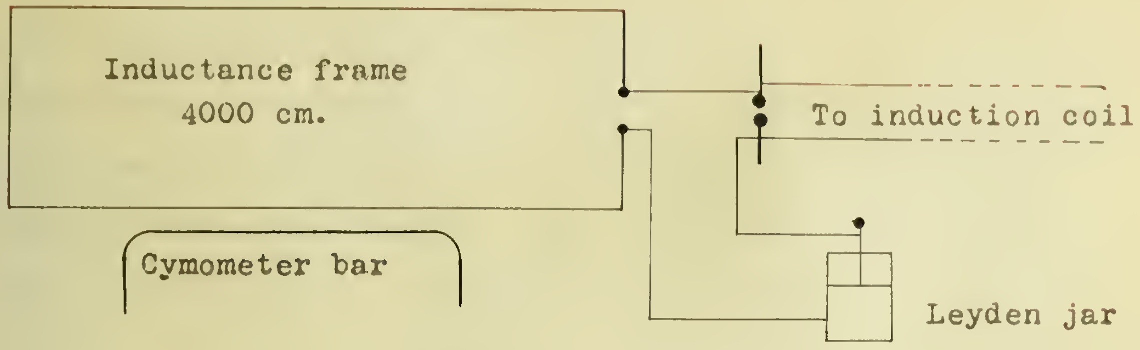


Fig. 33.

ine or an induction coil. The cymometer is placed with the portion efg of the copper bar parallel to one side of the inductance frame and a few inched from it, and the handle is moved until a maximum glow is produced in the neon tube, or a maximum deflection of the galvanometer is obtained. In measurements of this kind where only small amounts of energy are used in the oscillation circuit, the galvanometer is the better indicator because of its sensitiveness. The value of the oscillation constant read from the cymometer scale is equal to $\sqrt{4000\ C}$, since the inductance of the oscillating circuit is 4000 cm. Solving for C, the capacity of the jar is obtained in microfarads. Knowing the value of C, the value of an unknown inductance may then be found by connecting it in series with the oscillating circuit, and the oscillation constant obtained for the new resonance position. The new value of the oscillation constant will be equal to $\sqrt{(4000 + L)\ C}$, where L is the only unknown quantity and can be solved for. This value for L will be expressed in centimeters.

To obtain resonance curves by means of the cymometer$_{31}$, the thermal junction is used in connection with the galvanometer as an indicator. The galvanometer is calibrated by connecting the resistance wire in series with a calibration rheostat and a milliam-

meter furnished for the purpose, and a secondary cell. Known currents are passed through the resistance and the corresponding deflections of the galvanometer noted. Plotting deflections of the galvanometer as abscissae and milliamperes as ordinates, a calibration curve is obtained. The cymometer is brought up to the oscillating circuit as in Fig. 33, and deflections of the galvanometer noted for different positions of the handle. The corresponding frequency or wave-length is also observed and noted. Near the position of resonance the readings are taken at smaller intervals, since the deflections will increase rapidly as the two circuits approach the condition of resonance. Plotting cymometer currents as ordinates, and wave-lengths or frequencies as abscissae, the resonance curve is obtained. From these resonance curves, the decrements of the circuits may be obtained by Bjerknes' method.[29]

TUNING A SENDING STATION.

The experimental part of the work consisted in the construction of a practical wireless telegraph station (Fig. 34) of the inductively coupled type, and the determination of the wave-lengths sent out from the antenna when the transmitter circuits were in resonance. The measurements were made by means of the Fleming cymometer which has been available for the purpose.

The antenna consists of four parallel wires each 180 feet in length. These wires are held at a distance of two feet apart by a spar at each end, from which the wires are insulated by ten-inch ebonite insulators. A transverse wire at each end of the antenna connects the four wires together, and a single heavy copper wire connects the lower end of the antenna with the main switch inside the station. The antenna wires are of No 14 phosphor bronze wire,

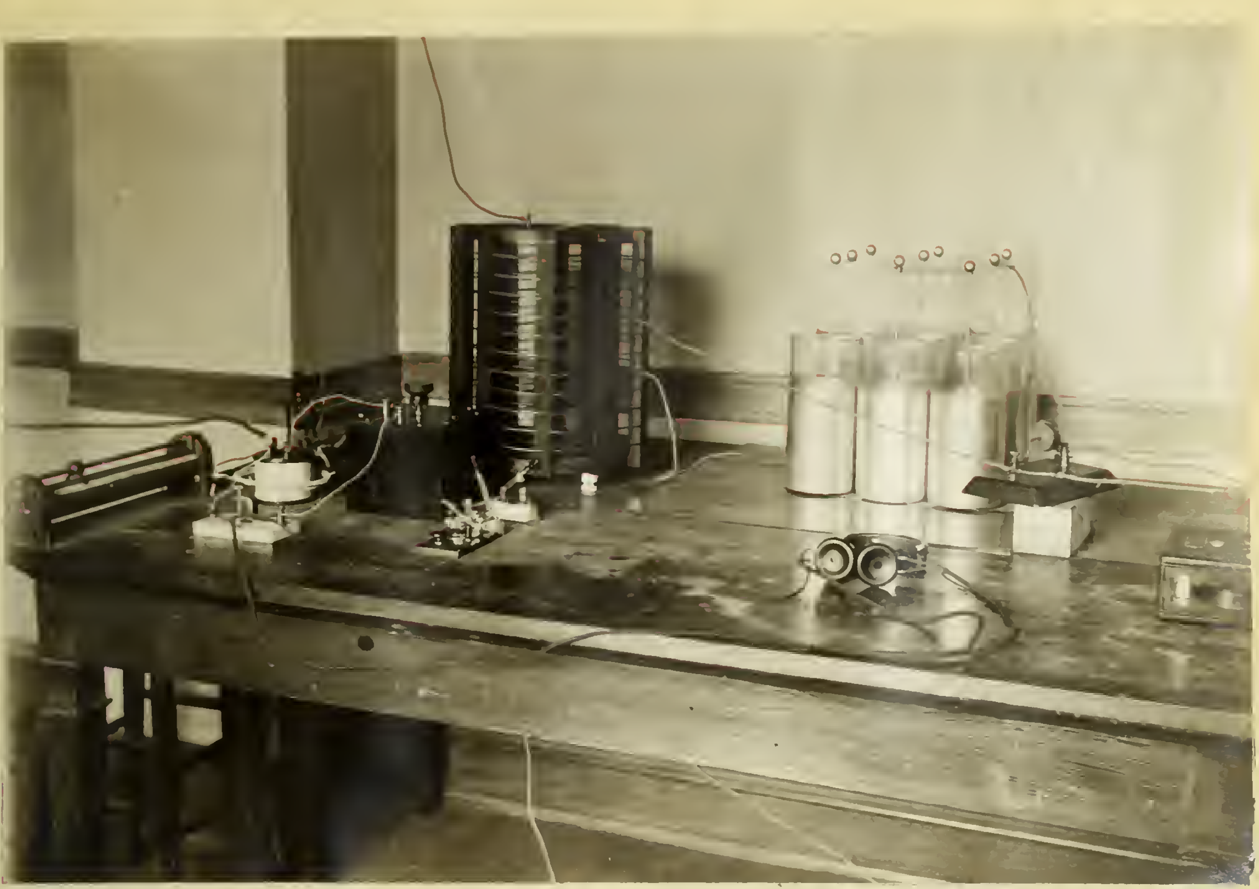


Fig. 34.

this material being used because of its light weight and great tensile strength. The portion of the leading-in wire inside the station is stretched horizontally to permit the use of the cymometer in measuring the wave-lengths of the antenna circuit. The antenna itself is hung from the top of the old University stack and stretched across to the third story of the Physics building.

The connections for the sending apparatus are shown in Fig. 35. The primary circuit consists of the spark gap G, connected in series with a battery of Leyden jars C, and the primary L_1 of the sending transformer. The Leyden jar battery consists of nine jars connected in parallel, and the primary of the sending transformer of nine turns of heavy copper wire spaced one inch apart and wound on a wooden cage fourteen inches in diameter. The cir-

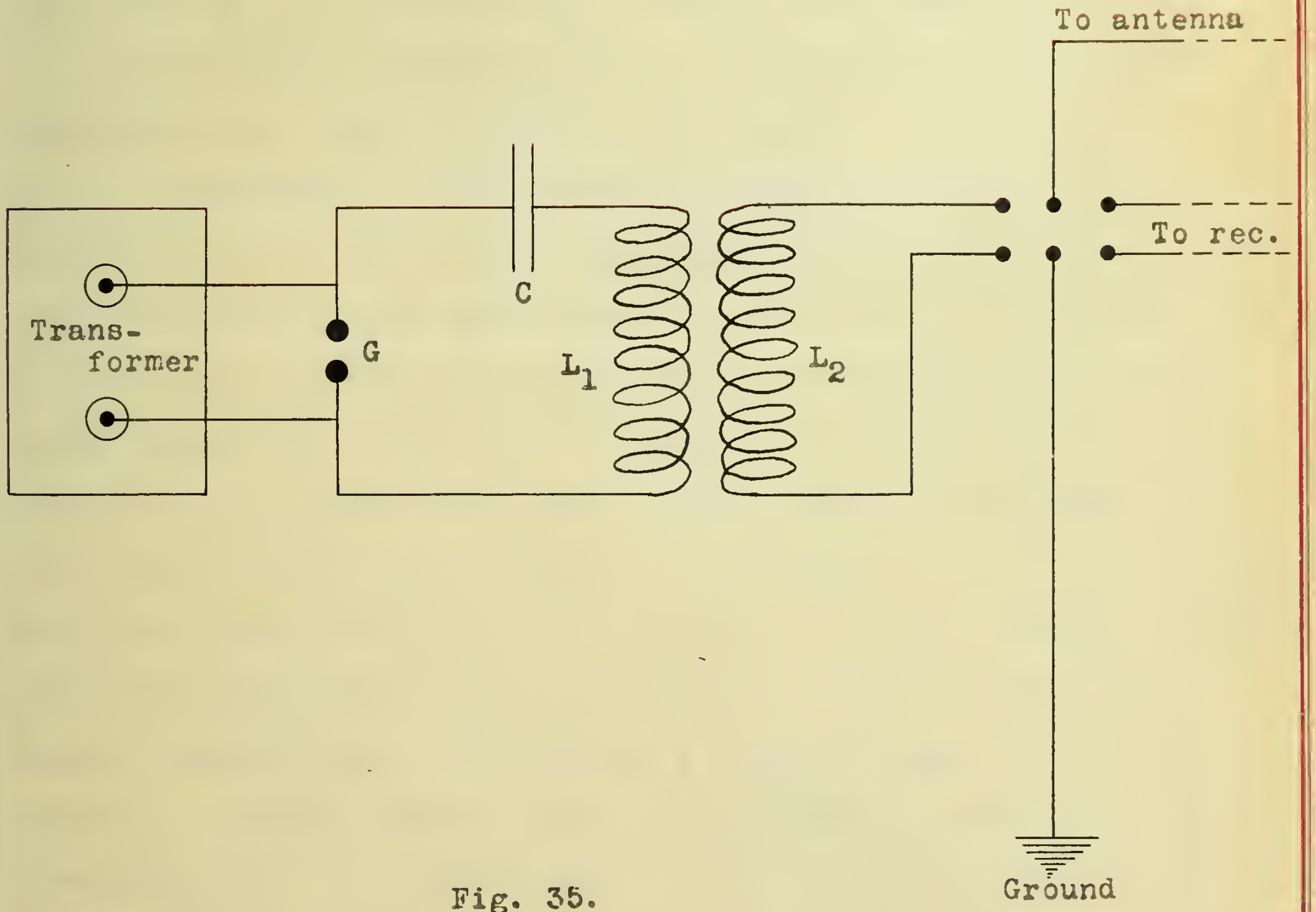


Fig. 35.

cuit is charged by a two kilowatt transformer whose secondary terminals are connected in series with the spark gap.

The secondary circuit consists of the antenna, the secondary of the sending transformer, and the ground connection, all in series. The secondary L_2 of the sending transformer is made up of twenty three turns of bare copper wire spaced about three-quarters of an inch apart, and wound on a wooden cage nine inches in diameter. The upper end of this coil is connected to the antenna and the lower end to the ground wire through the antenna switch.

The receiving apparatus (Fig. 36) is similar to the sending apparatus except that it is much more compact, since it is not subject to high potential oscillations. Also the closed circuit contains a detector instead of a spark gap. The primary circuit in a receiving set is the open circuit, consisting of the antenna, the primary coil of the receiving transformer, denoted by P, and the ground connection. The coil P is made up of several turns of insulated No. 14 copper wire wound in the form of a ring about six and one-half inches in diameter. Also there is a coil k in series with the antenna and the coil P. This coil is two inches in diameter and twelve inches long, and is closely wound with No. 20 insulated copper wire. The effective length of this coil may be varied by a double spring contact which slides along a brass rod above the coil. The insulation of the wires is stripped off so as to permit the springs to make contact with the wires of the coil. This coil k is known as the "tuning coil", and is used to vary the length of the antenna circuit.

The closed, or secondary, circuit contains the detector, a variable rotary condenser by which the circuit is adjusted to resonance with the antenna circuit, and the secondary coil S of the

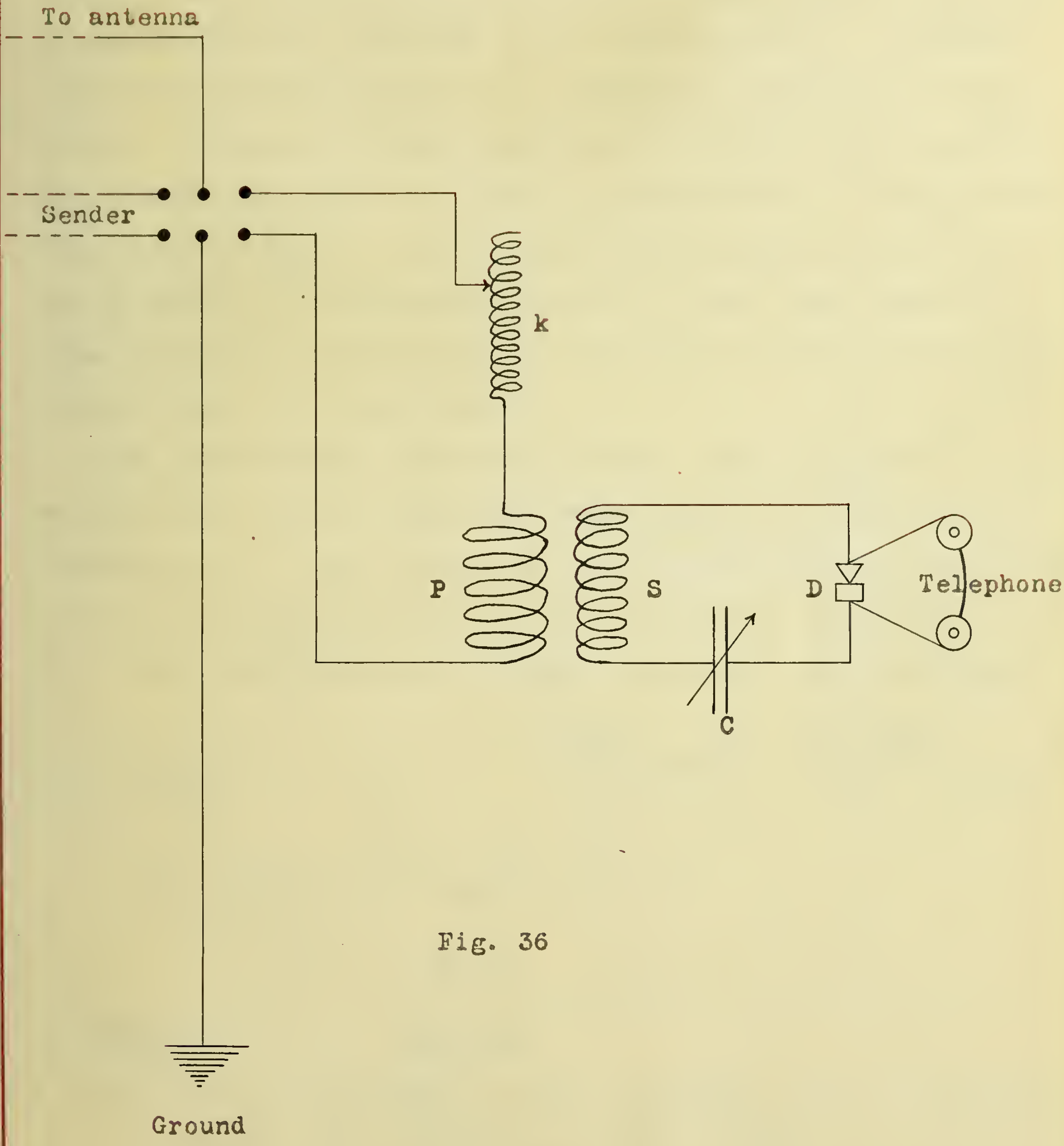


Fig. 36

receiving transformer. The coil S is of No. 18 insulated copper wire closely wound on a wooden spool three and one-half inches in diameter and two and one-half inches in length, and is connected in series with the condenser C, and the detector D. A double head-band telephone receiver is connected in parallel with the detector in order that the signals may be heard by the operator. The detector consists of a piece of galena crystal with which the connection is made on one side by a screw clamp that holds the crystal in position on the marble base and on the other side by a fine steel wire which extends from the opposite binding post and presses against the side of the crystal.

As stated above, the energy for the sending circuit is supplied by a two kilowatt transformer which operates on the 110-volt lighting circuit, and transforms it to 25,000 volts. The connections of the primary circuit of this transformer are shown in Fig. 37. When the sending key is open, the current passes through the

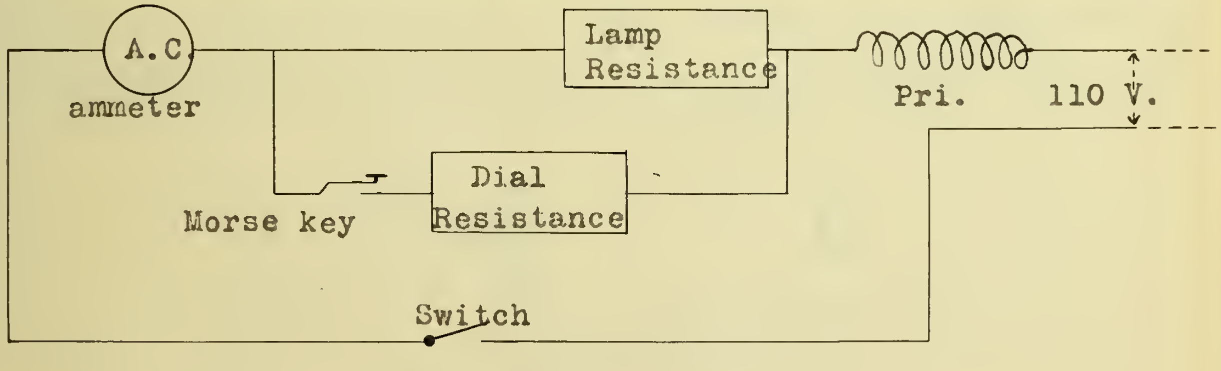


Fig. 37.

primary of the transformer, a lamp resistance, and an alternating current ammeter, all connected in series. The lamp resistance is such that the current is not strong enough to charge the condensers to a sufficiently high potential to break down the spark gap. By closing the key, a dial resistance is thrown into the circuit in parallel with the lamp resistance and their combined resistance is

less than one-half the resistance of the lamps alone, the increased current charging the condensers to the discharge potential. The resistance of the spark gap then breaks down and sparks pass, producing oscillations in the sending circuit. This arrangement of the power circuit is used to prevent the burning out of the contacts of the sending key when large currents are used in the circuit.

In measuring the wave-length of the antenna circuit, the closed circuit of the sender was disconnected and removed and the antenna, the secondary coil of the sending transformer, and the spark gap were connected in series with the ground connection. The cymometer was placed in position with the copper bar parallel to the leading-in wire and about one foot from it, and the circuit set to oscillating. The cymometer was then adjusted to resonance, and the wave-length was found to be 650 meters.

To measure the condenser circuit, the secondary circuit was disconnected, and the primary circuit was again connected up with the secondary coil of the sending transformer removed. (Fig. 38)

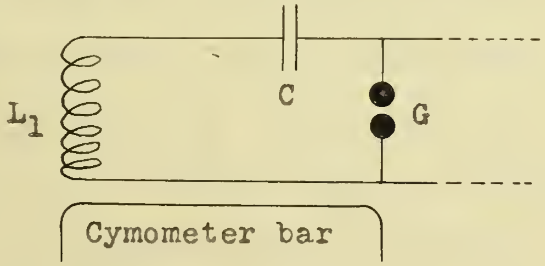


Fig. 38.

The cymometer was placed in the position shown, and the wave-lengths measured for different numbers of turns of the inductance. The results of these measurements appear in the table on the following page. For three turns of the inductance, the wave-length of the condenser circuit was found to be 650 meters, the same as that of

Wave-Lengths of Condenser Circuit.

(Nine Leyden Jars.)

Turns on Primary Coil.	Wave-Length in Meters.
1	445
2	550
3	650
4	770
5	880
6	980
7	1060

the antenna circuit. The two circuits of the sender were then replaced and the cymometer set in position before the antenna wire as in the former case. Oscillations were set up in the sender, and the cymometer was adjusted to resonance. In this case, two maxima were observed, one for a wave-length of 710 meters, and one for 580 meters. This result is in accordance with the theory, and means that the antenna is sending out two waves, for either of which a receiving station may tune. The longer wave, as indicated by the neon tube, was much stronger than the shorter wave, and hence could be detected at a much greater distance. Using four turns of the primary coil, the wave-lengths were 800 and 600 meters, but the intensity was reduced to less than half the intensity of the 710-meter wave obtained when the circuits were in resonance. Obviously the use of the two circuits otherwise than in the resonance condition would result in a useless waste of energy.

As a rule, receiving stations are not calibrated. The adjustments for different wave-lengths are made so readily by means of the tuning coils that there is no advantage in calibration. The shortest wave of known length received over the apparatus described is somewhat below 700 meters. With the transformer disconnected and the condenser and detector connected in series with the antenna, a message sent to Key West by the S.S. Advance was

intercepted. According to the United States government list of wireless telegraph stations, the Advance uses a wave-length of 425 meters. No other stations having a listed wave-length have been identified.

The problem of interference has only been partially solved by the use of tuned systems. Where two or more stations have the same wave-length, as frequently happens for stations on the sea coast, signals cannot be received from either station unless the sparks have a considerably different pitch. This pitch is obtained by using high frequency generators, and by special forms of spark gap. With the increasing number of amateur and experimental stations that have been set up in the neighborhood of commercial stations, the interference has been such that service has been practically suspended for hours. At present the only remedy for this evil seems to be in legislation which will prohibit the erection of sending stations unless authorized by government license.

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telegraphy. Dr. Zenneck is one of the most prominent wireless telegraph engineers in Germany, and this work contains the results of many important investigations made by him. His "Leitfaden der Drahtlosen Telegraphie" contains some newer features, but is not so complete, merely stating the results arrived at by himself and other investigators. Both works are written in German.

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